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Optimized Volumetric Scanning for X-Ray Array Sources

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Engineering FY09 Technology Report

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Project Overview

Non-destructive evaluation (NDE) is the science and technology of determining non-invasively the internal structure of manufactured parts, objects, and materials. NDE application areas include medicine, industrial manufacturing, military, homeland security, and airport luggage screening. X-ray measurement systems are most widely used because of their ability to image through a wide range of material densities (from human tissue in medical applications to the dense materials of weapon components). Traditional x-ray systems involve a single source and detector system that rotate and/or translate about the object under evaluation. At each angular location, the source projects x-rays through the object. The rays undergo attenuation proportional to the density of the object's constitutive material. The detector records a measure of the attenuation. Mathematical algorithms are used to invert the forward attenuated ray projection process to form images of the object. This is known as computed tomography (CT).

In recent years, the single-source x-ray NDE systems have been generalized to arrays of x-ray sources [1]. Array sources permit multiple views of the object with fewer rotations and translations of the source/detector system. The spatially diverse nature of x-ray array sources has the potential of reducing data collection time, reducing imaging artifacts, and increasing the resolution of the resultant images. Most of the existing CT algorithms were not derived from array source models with a spatially diverse set of viewing perspectives.

Project Goals

Single-source x-ray CT data collection, processing, and imaging methods and algorithms are not applicable when the source location is expanded from one dimension (a rotating and/or translating point source) to two (a rotating and/or translating array). They must be reformulated. The goal of this project is to determine the applicability of x-ray array sources to problems of interest to LLNL and its customers. It is believed array source data collection will be faster while yielding higher resolution reconstructions with fewer artifacts. There are three tasks in the research

1. Develop forward array source analytic and computational models;
2. Research and develop array source reconstruction algorithms;
3. Perform experiments.

Relevance to LLNL Mission

X-ray CT is an essential tool in LLNL's NDE area. X-ray array sources constitute leading edge technology in NDE. Their role in maintaining LLNL's NDE leardership must be determined.

FY09 Accomplishments and Results

Two phantoms have been selected as canonical objects for the project: an alternating cylindrical stack of flat Teflon and balsa wood plates known as a "Defrise" phantom [2], and cylindrically symmetric nested phantom of epoxy, aluminum, and air known as the "As-Built" phantom. The Defrise phantom, for which data exist, serves as a contrast and resolution object.

CTSIM (a LLNL x-ray ray-tracing transmission code) has been integrated into MATLAB. It has been used to model a stacked cylinder proof-of-concept and Defrise data.

A successful model-based inversion has been achieved with the stacked cylinder proof-of-concept model which compared reconstructions of pristine and damaged objects. A simulated “defect” inserted in the damaged object was identified and located (see figure 1).

A collaboration with Stanford University has been established. Real Defrise phantom data have been obtained and successful reconstructions achieved using model-based and voxel-based (ordered subset expectation maximization [3]) algorithms (see figure 2).

A collaboration with array source research, development, and manufacturing companies (Triple Ring and NovaRay) is forming to acquire future area array source data (see figure 3).

FY10 Proposed Work

A new Defrise phantom will be designed and manufactured at LLNL. The metrology (ground truth) does not exist for the Stanford University Defrise data resulting in the lack of objective metrics for the current reconstructions.

Data will be collected on the new Defrise and “As-Built” phantoms at Triple Ring. Source and detector characterization measurements will be performed.

Source and detector characterization algorithms, and remediation methods will be developed.

Research into inversion and imaging algorithms will continue.

Related References

[1] Bruno De Man, Samit Basu, Dirk Bequé, Bernhard Claus, Pete Edic, Maria Iatrou, James LeBlanc, Bob Senzig, Richard Thompson, Mark Vermilye, Colin Wilson, Zhye Yin, Norbert Pelc,"Multi-source inverse geometry CT : a new system concept for X-ray computed tomography," Medical Imaging 2007: Physics of Medical Imaging Proc. of SPIE Vol. 6510

[2] M. Defrise and R. Clack,"Filtered backprojection reconstruction of combined parallel beam and cone beam SPECT data," Phys. Med. Biol. 40 (1995) 1517-1537

[3] H. M. Hudson and R S Larkin, "Accelerated Image Reconstruction using Ordered Subsets of Projection Data," IEEE Transactions on Medical Imaging 1994

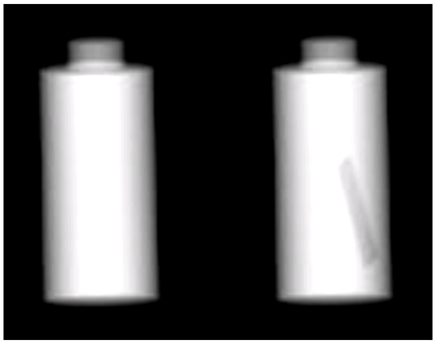

Figure 1. Simulated data used in model-based reconstruction of the proof-of-concept stacked cylinder model. The object on the left is pristine while the object on the right contains a parallelepiped “defect” which was identified and located.

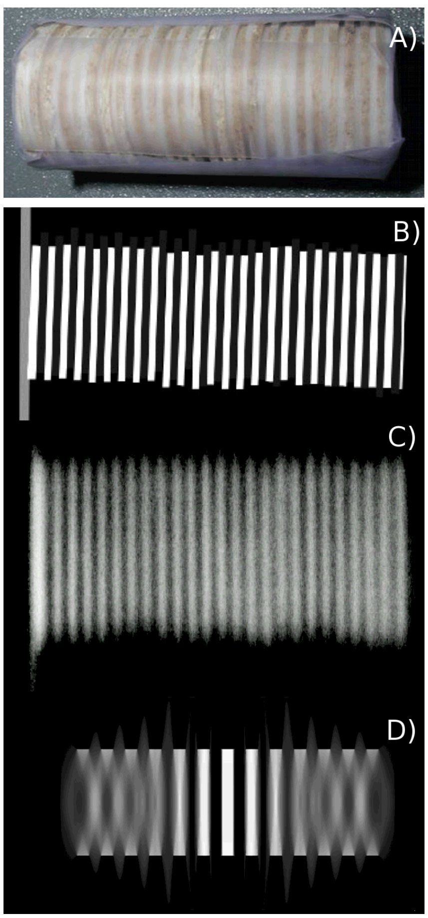

Figure 2. A) Photograph of the Defrise stacked plate phantom. B) Model-based reconstruction. C) Ordered-subset expectation maximization (OSEM) reconstruction. D) Traditional reconstruction of simulated Defrise phantom data. Note: reconstruction of the real data using a traditional (cone-beam) algorithm failed. Simulated data were used to demonstrate the blurring and loss of resolution when compared with the model-based and OSEM algorithms.

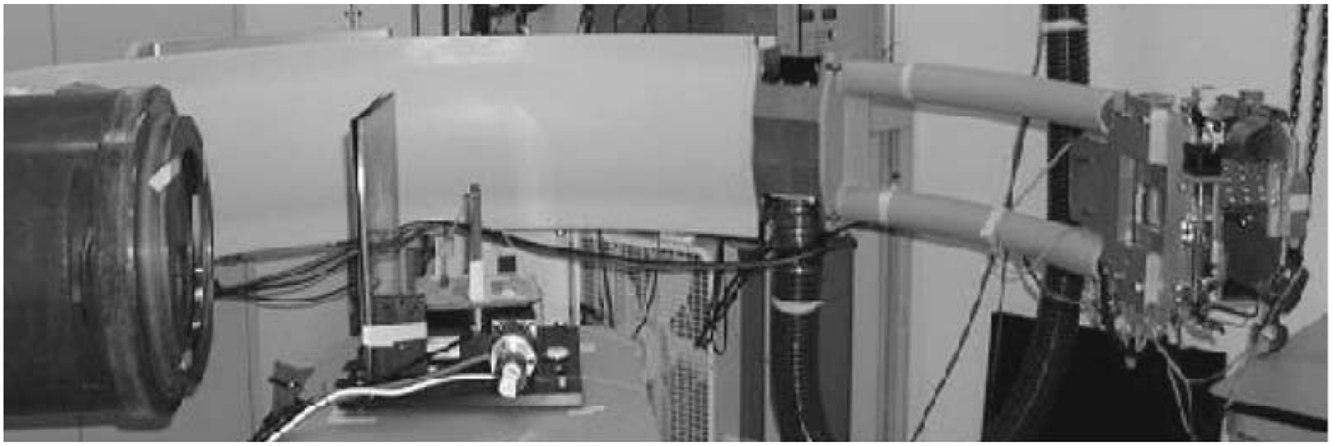

Figure 3. Photograph of the x-ray array source and array detector system designed and developed by industrial collaborators NovaRay and Triple Ring.